TO SUPPORT A MOUNTAIN (A)

Design & Development of a "Dynamic" Mine Prop

This case history is intended for use in teaching engineering design. It consists of four parts, with suggested questions after each part. We recommend that Part B be issued to the students only after they have completed the assignments connected with Part A, and so on with successive parts.

This case study was one of a series developed by the Department of Engineering at the University of California, Los Angeles, through its Educational Development Program, with the help of funds from a Ford Foundation grant. We gratefully acknowledge the help given by the members of the Department and the very generous cooperation of the owners and employees of Ledeen, Incorporated.

H.O. Fuchs
March 1964

Reprinted from EDP Report Number 6-64. Written by R. B. McKee

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Ledeen, Inc. is located in El Monte, California, a stone's throw from the San Bernardino Freeway. The company was founded in 1934 by Hyman Ledeen to market mechanical power transmission equipment. Manufacture of pneumatic and hydraulic cylinders began in 1948. At present, Ledeen produces air-operated and oil-operated valve control mechanisms and valves for the natural gas pipeline industry (sold as a package unit with controls), and the "dynamic" mine prop which is the subject of this report.

Mr. Hyman Ledeen (BSME, University of Colorado, 1920), the company's President; Howard Ledeen (BSME, Stanford University, 1943; MSME, Stanford, 1947), Vice-President; and three others make up the engineering staff. The machine shop employs about 50 people. It is equipped for conventional machining, welding, and specialized finishing operations.

Howard Ledeen has been responsible for the design and development of the "dynamic" mine prop since its inception. Mr. Hyman Ledeen follows a management principle which requires a maximum delegation of authority. The decisions credited to Howard Ledeen and other employees of the company were usually, but not necessarily, concurred in by the company's president.

Support of Mine Walls and Roofs

Traditionally, mine shafts and tunnels have been supported by wooden timbers. This is due to more than just availability. The natural ductility of wood is a vital safety factor.

Rock and compacted earth have characteristics similar to concrete; capable of resisting great loads in compression, they are relatively weak in tension. Thus, when an unsupported tunnel is created in solid earth, a natural arch will form as the material in tension falls out. The roof support props must hold only this amount of material.

Very few mine workings are located in solid, homogeneous bodies of rock and earth. The usual formations are layers or strata of rock, gravel and earth. The layers are tipped and fractured. Such formations will tend

to "close up" mine tunnels or other man-made holes. These massive earth motions cannot be resisted by any sort of prop. The practical miner's solution to this problem is a prop which, like wood, will yield and stay in place during the motion. A wooden post, under compression, tends to spread due to buckling of internal fibers, putting the outer fibers in tension. When a mine foreman taps the column with a hammer and sees splinters fly, he knows that the roof is moving down.

In recent years, mine props made of metal have been widely used in the coal mines in Europe. Most of these props operate by friction, created by a wedge manually driven in. When the load on the prop reaches a certain value, the friction surfaces slide, providing the yielding action needed.

The friction prop is the least expensive of adjustable metal props. Despite a higher purchase price ($16-30, compared with $0.40 for a wood prop) the use of metal props has resulted in much lower mining costs because the metal prop is quickly set up and removed, and because only 7-8% of the props have had to be replaced each year. However, the yielding load is not reliable, and there is no way, short of collapse, for the friction prop to indicate the load placed upon it.

Most of the deficiencies of the friction prop are eliminated in the hydraulic props made in England, France and Germany. These are essentially the same as the hydraulic jacks used for automobiles, with a valve provided to dump hydraulic fluid or return it to a reservoir at a predetermined pressure, thus providing a precise and reproducible yielding force. The jack is raised and preloaded either from an external reservoir or by a built-in pump.

The second principal reason for the use of hydraulic mine props is the "long wall caving" technique of mining in which a line of props is removed at a time, allowing the rock or "gob" which they support to fall to the floor. The props removed are replaced in the rear. This technique of mining requires a roof support which may be removed and set up very quickly, and whose length may be adjusted to fit the roof height without changing the support characteristics. This productivity has justified the higher price ($33-95) of the hydraulic props, which are made in Western Europe by about 50 manufacturers.

The Need for a New Type of Mine Prop

Ledeen's sales representative in the New Mexico area was Mr. Jerry Miller, a former mine superintendent. He had perceived some problems of American mining which he felt that Ledeen was in a good position to solve. Mr. Miller's suggestion was that Ledeen, Inc., offer a pneumatic cylinder for use as a mine prop. Howard Ledeen, after a further analysis of the problems of application and use, established the following design requirements:

1. Provide a support for the rock overhead which would follow earth motion with little change in force.
2. Provide support for rock formations which are not "strata-oriented". That is, the prop must function in other than vertical placement.
3. The prop must stay in place under the concussion loads caused by blasting.
4. The prop should be useable as an anchor post from which to operate winches, etc.
5. The prop must be easy to remove, since its cost will require re-use.
6. The prop should be modular; i.e., fit readily into standard pipe columns.

Feasibility Study

It was soon apparent to Howard Ledeen and his co-workers that it would require an extraordinary pneumatic cylinder to provide the support force (10-15 tons or more) required for most applications. To develop such forces with the usual (80-100 psi) air pressure available in a mine would require a piston of 200 square inches. Furthermore, the use of high air pressure is hazardous (mixtures of air and oil in a cylinder will ignite if suddenly compressed) and the piston rod in a standard double acting air cylinder is not large enough to support such loads in compression. Finally, the specialized valving needed to provide controlled yield and prevent leakage would prohibitively increase the cost.

Since so many problems had attached themselves to the use of pneumatic (air) cylinders, the engineers decided to use a hydraulic jack, in which the required forces can be achieved in a smaller, more easily handled quantity of fluid. The required "dynamic" action (ability to shorten or extend with small changes in force) was to be provided by the use of an external gas accumulator, a commercial unit simply piped into the jack itself.

This accumulator was a tank in which gas under pressure surrounds a flexible bag connected to the hydraulic cylinder. Because of the low "spring rate" of the gas, the bag can accept or discharge oil without large pressure changes. The jack was made only long enough to provide a range of support motion and set into a piece of standard pipe which served as the main column.

During the feasibility study, an additional feature was conceived; the pressure inside the jack could serve as an indication of the support load. Therefore, a pressure gage was mounted on the outside of the unit.

Prototype Testing

The first unit performed very well, but would not withstand the effects of nearby blasting; the pressure gage and external accumulator were immediately carried away. Mr. Ledeen decided to design an accumulator within the jack itself, and to use a removable pressure gage.

QUESTIONS - PART A

1. In what ways do the feasibility study just described (and your own deductions) change the design criteria for the new roof support?

2. Design a roof support to satisfy these criteria with enough detail that a prototype may be built from your plans. The statement of needs are expanded and/or modified into design criteria by the designer as he proceeds through the design process. Be sure to take account of all modes of failure and check with the original statement of needs as you proceed.

ECL-129B

TO SUPPORT A MOUNTAIN

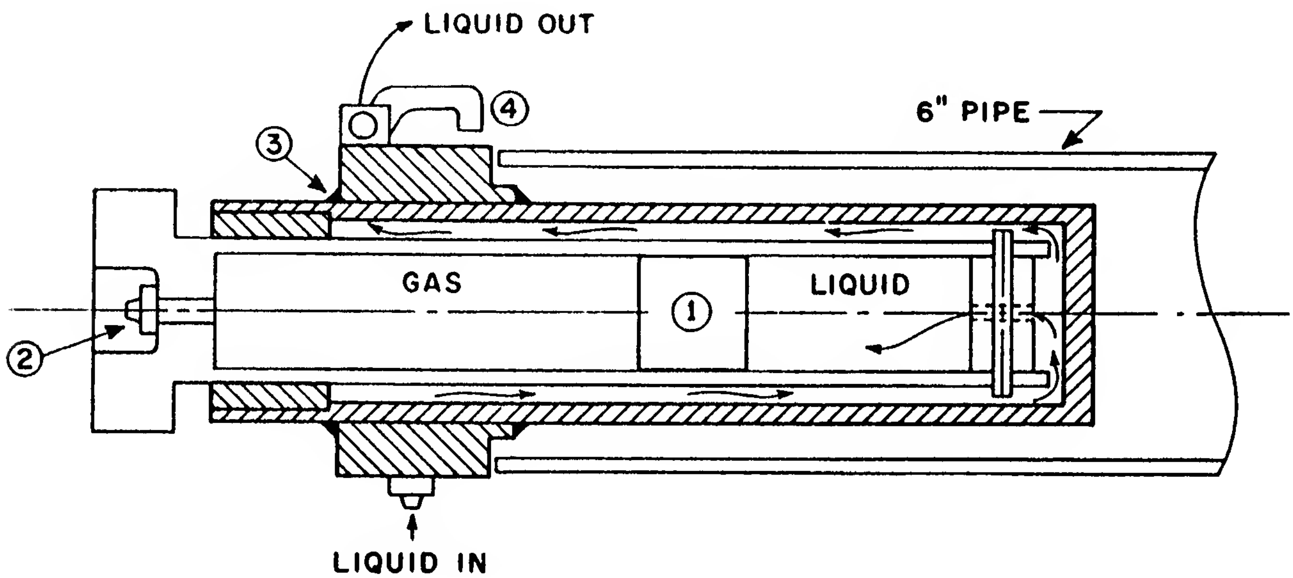
Part B

First Production Design and Field Experience

Reprinted from EDP Report Number 6-64. Written by R.B. McKee.

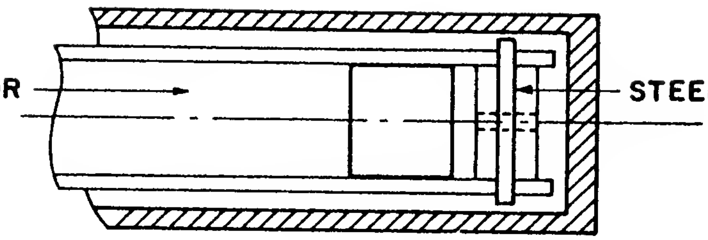
First Production Design

The first production Dynaprop roof support, Model 300, was basically a single acting hydraulic cylinder. A piston (1) sliding freely within the moving cylinder acts as an accumulator by separating the hydraulic fluid, which operates the cylinder, from the nitrogen which is introduced through the charging valve (2). The housing for the unloading and relief valves (3), welded to the outside case, fits into and rests on the top of a standard 6" diameter pipe.



The unloading valve used in this first model was a standard hydraulic check valve modified to operate as an unloading valve. When the release handle (4) is raised, the release valve is forced off its seat against hydraulic pressure. (See Part D of this report, "The Spanseal Unloading Valve.")

An accident occurred during disassembly of one of these units. The end of the accumulator cylinder is closed by a block held in place with a steel pin. In operation the accumulator had been filled with nitrogen at 1000 psia. When the pin was removed during disassembly, the block and accumulator piston behaved much like the pellet in an air gun. Fortunately, no one was hurt. This incident led to a design change (see Model 510).



Materials of Construction

Although the roof prop is necessarily a portable device and should not be too heavy to be carried by a man, the primary requirements are safety and reliability. For this reason, the cylinder body and piston were made of medium carbon (SAE 1040) steel. The piston rod gland was Meehanite (cast iron). A commercial dry film lubricating process was used.

The piston rod was chrome plated and finish ground to a 16 rms finish. Sealing was by means of rubber "O"rings with backing discs of Teflon fluoro carbon plastic.

QUESTIONS REGARDING MODEL 300

1. Evaluate the design of the model 300 in terms of design stresses, buckling stability and force required to operate the unloading valve. The rated load of the model 300 Dynaprop is 12 tons.

2. Estimate the retraction time under
   (a) constant 2 ton load
   (b) 12 ton load diminishing to 200 lb.

3. Redesign the unloading mechanism (and valve, if necessary).

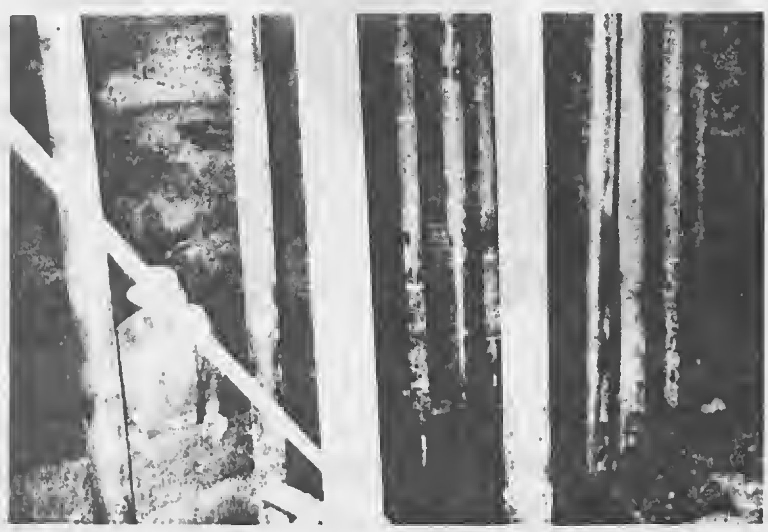
4. Devise a procedure to disassemble the accumulator while it is filled with air under pressure.

5. Why is it better to have the snap ring (45) strike the gland than the retaining pin (26), should the piston be extended too far?

Production and Use

Blast Caving

The availability of a mine prop which would withstand blast effects has inspired new techniques in hard rock mining. In an adaptation of the "long wall caving" technique used in coal mining, a line of props is set up parallel to the wall which is to be mined. Planks are laced to the props to form a wall.



Then the wall of ore is drilled and blasted. The wall of planks has kept the blasted fragments of ore within the space between the row of props and the rock wall. The next operation, known as "slushing", is the removal of the broken rock (known as "muck") from the trench formed by the rock face and the laced props. This technique, besides the improvement of mining efficiency brought about, permits a closer control of the location from which the ore is removed. The latter is especially important in the gold mines of South Africa, in which the ore veins are thin (about 40" high) and very deep in the earth. The usual practice in South Africa is to use old conveyor belts as lacing, because of their resiliency.

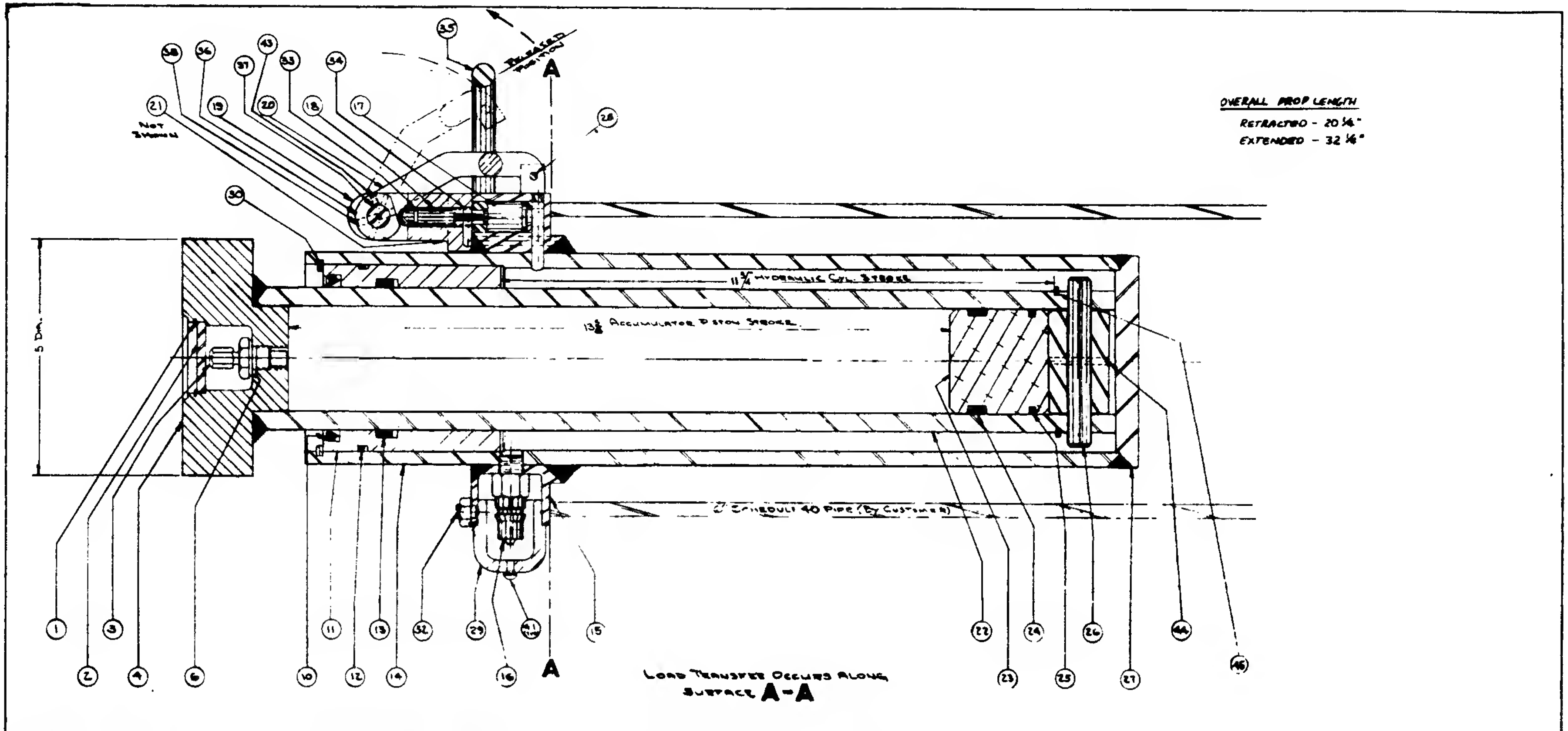
Field Experience

The use of Dynaprop roof supports very close to blasting operations has resulted in damage to the release handles and other external fittings. After blasting operations, the rock being supported may become extensively fractured and unstable. When the pressure in the prop is released, the prop must retract very quickly or be lost in the resulting collapse. The same can be said of the miner who is trying to salvage the prop.

The pipe at the far left has been used as a slusher block anchor post. (Note the bend.) Also observe the Dynaprops in the base of the pipe supports.

A glance at the illustrations will show the sort of environment in which mine props must function. The piston rod seal must include a scraper element to exclude dirt, and all components must be essentially rust free.

All Dynaprops are precharged with nitrogen, which is used for its inertness. The hydraulic fluid used depends upon local requirements. For instance, in the deep, hot, gold mines of South Africa, the use of oil would create a severe fire hazard, so water with a soluble lubricant is used in the Dynaprops. In the potash mines of Carlsbad, New Mexico, water would react with the potash; oil is used "for safety". The potash mines are an exception, however -- most of the future applications of the Dynaprop are expected to require a water-base hydraulic fluid.



ITEM	NO REQ	DESCRIPTION	ITEM	NO REQ	DESCRIPTION	ITEM	NO REQ	DESCRIPTION
1	1	SNAP RING	17	1	UNLOADING VALVE	33	1	ACTUATING PIN SEAL
2	1	GUARD PLATE	18	1	ACTUATING PIN	34	1	ACTUATING PIN SPRING
3	1	GAS CHARGING VALVE	19	1	ACTUATING PIN HOUSING	35	1	RETAINING EYEGUARD (INTEGRAL W/ 18)
4	1	FRICTION HEAD (INTEGRAL W/ 22)	20	1	UNLOADING HANDLE	36	1	UNLOADING VALVE CAM
			21	4	CAP SCREW	37	1	CAM PIN - UNLOADING VALVE
6	1	CHARGING VALVE SEAL	22	1	PISTON ROD	38	3	RETAINER PIN - UNLOADING HANDLE
			23	1	ACCUMULATOR PISTON			
			24	1	PISTON SEAL			
			25	1	PISTON RING	41	3	CHAIN RETAINER SCREWS
10	1	SCRAPER RING	26	1	STOP PIN	42	2	RETAINER CHAIN
11	1	GLAND	27	1	REAR HEAD (INTEGRAL W/ (14))	43	1	CAM SET SCREW
12	1	GLAND SEAL	28	1	SAFETY INTERLOCK PIN	44	1	HYDRAULIC SNUBBER
13	1	PISTON ROD SEAL	29	1	GUARD CAP	45	1	PLUNGER SNAP RING
14	1	TUBE	30	1	SNAP RING - GLAND RETAINER			
15	1	THRUST FLANGE (INTEGRAL W/ (14))						
16	1	HYDRAULIC CHARGING VALVE	32	1	GUARD CAP RETAINER			

GAUGING TOOL FOR PRESSURE TESTS WHILE DYNAPROP IS UNDER LOAD IS AVAILABLE.

LEDEEN DYNAPROP ROOF SUPPORT MODEL 300

NONE D-10604-R4

(FILE DYNAPROP)

ECL 129C

TO SUPPORT A MOUNTAIN

Part C

Modification and Redesign

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Design Modification - Model 300

If you examine the "Revisions" box in the lower right corner of the drawing of Model 300, you will see that the design was modified several times during 1962. First, the passage for hydraulic fluid in and out of the accumulator was reduced to a small hole drilled in the block which holds in the accumulator piston (44) . This performs the function of a "shock absorber

To provide a more dependable hydraulic and mechanical joint, the friction head was welded on to form the top of the accumulator.

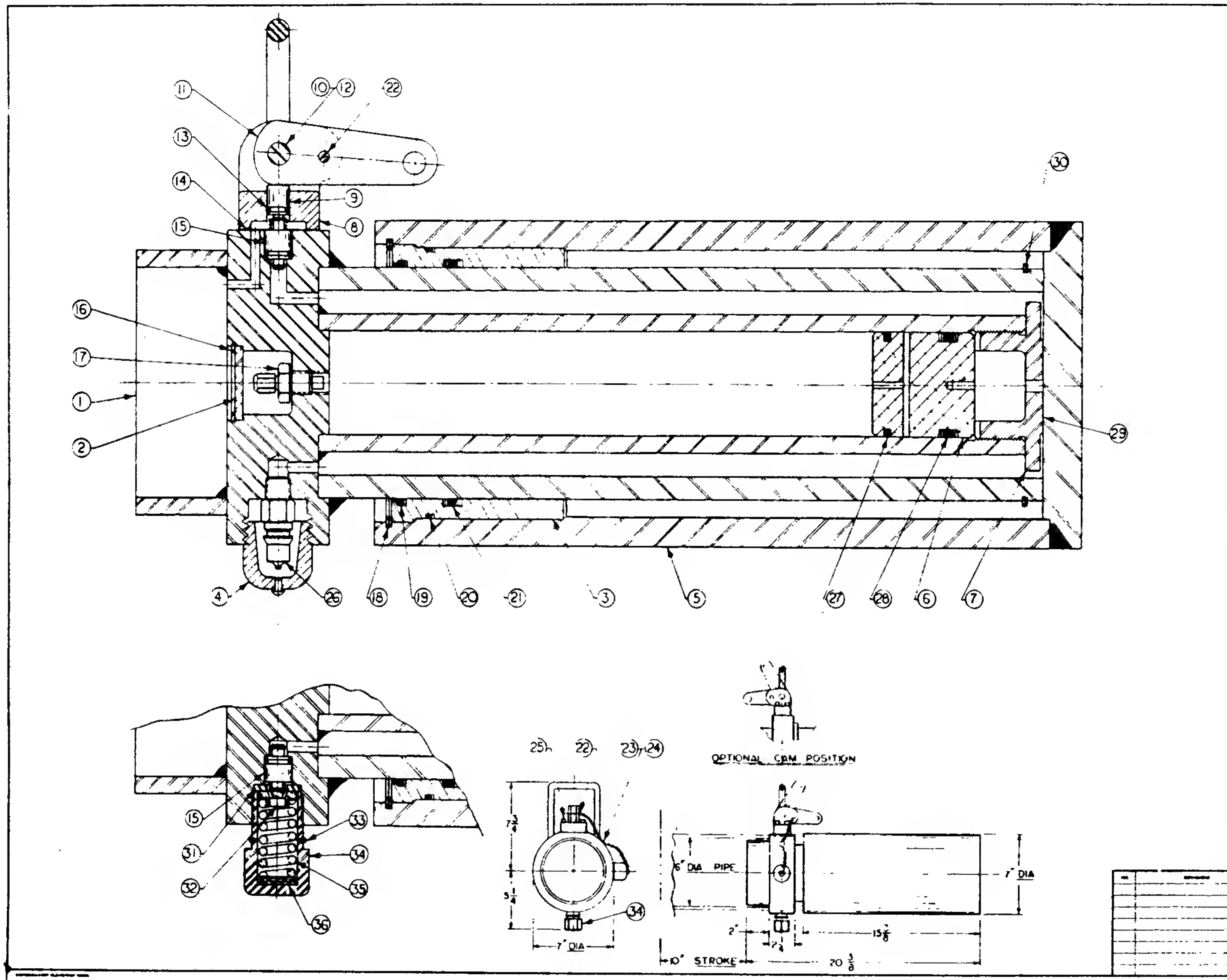
To prevent the piston from moving so far out of the cylinder that the pin (26) would strike the gland (11) , a snap ring was placed on the piston to stop the motion. Finally, the commercial relief valve was replaced by a new type specifically designed for the mine prop. (See Part D dealing with the e release valve.)

Redesign - Model 510

The maximum diameter of the Model 300 support (and, therefore, the maximum capacity for a given hydraulic pressure) was limited by the fact that the accumulator and main cylinder had to fit within a 6" pipe. Could the support be redesigned so that this restriction no longer applied? It could, and was.

The solution was to mount all of the operating parts of the Dynaprop outside of the pipe; only a stub fits within the support pipe. The Model 510 is rated at 40 tons, and has a double wall over the accumulator for safety.

Notice how the problem of disassembling the accumulator is handled. As the retainer is unscrewed, the accumulator piston sealing ring 28 moves off the cylindrical surface, allowing nitrogen pressure to leak off through the snubber hole while the threads are still engaged. The new Ledeen-made unloading valve, already used as a field modification, was designed into the Model 510. The same type of valve was adapted for use as a relief valve by simply spring-loading the valve against pressure. The decision to incorporate a relief valve followed incidents in which Model 300 supports were "inflated" by accidental overloads.



RELIEF VALVE SETTING:

FOR:

CRACKING PRESSURE	RE-SET PRESSURE	NUMBER OF SHIM 36
2600	2200	2
4300	3600	3
6000	5000	4

ITEM NO	REQ	DESCRIPTIONS
36	1	ADJUSTMENT SHIM - SET
35	1	RELIEF VALVE SPRING
34	1	" " BONNET
33	1	" " BONNET O-RING
32	1	" " SPRING GUIDE
31	1	RELIEF VALVE SPACER
30	1	ROD RETAINER RING
29	1	WARNING PLATE
28	1	PISTON SEAL
27	1	PISTON RING
26	1	HYDRAULIC CHARGING VALVE
25	4	CAP SCREW
24	2	CHAIN RETAINER SCREW
23	1	CHAIN
22	1	COTTER PIN
21	1	PISTON ROD SEAL
20	1	GLAND SEAL
19	1	SCRAPER RING
18	1	SNAP RING - GLAND RETAINER
17	1	GAS CHARGING VALVE
16	1	SNAP RING
15	2	UNLOADING VALVE CARTRIDGE
14	1	GASKET
13	1	O - RING
12	1	COTTER PIN
11	1	CAM
10	1	CAM PIN
9	1	ACTUATING PIN
8	1	ACTUATING PIN HOUSING
7	1	HYDRAULIC SNUBBER
6	1	ACTUATOR PISTON
5	1	HOUSING
4	1	GUARD CAP
3	1	GLAND
2	1	GUARD PLATE
1	1	PLUNGER

Ledeen Mfg Co.

LEDEEN DYNAPROP ROOF SUPPORT MODEL 510

ASSEMBLY AND PARTS LIST

M.E.C. 4-23-63 | FULL | D-82030

Redesign - Models 520 and 530

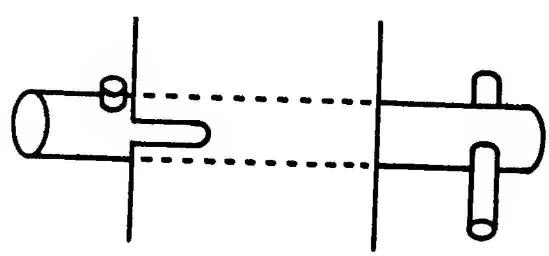
How can a hydraulic roof support be redesigned to give faster retraction? A simple and logical decision is to provide larger unloading valves to "dump" hydraulic fluid more quickly, and retraction springs to force it out.

The space required for internal retraction springs can be provided by reducing the stroke of the accumulator piston (Model 530). In order to have the same volume for the accumulator as before, its diameter must be increased. This was achieved by the sacrifice of the double wall construction of Model 510.

Model 530

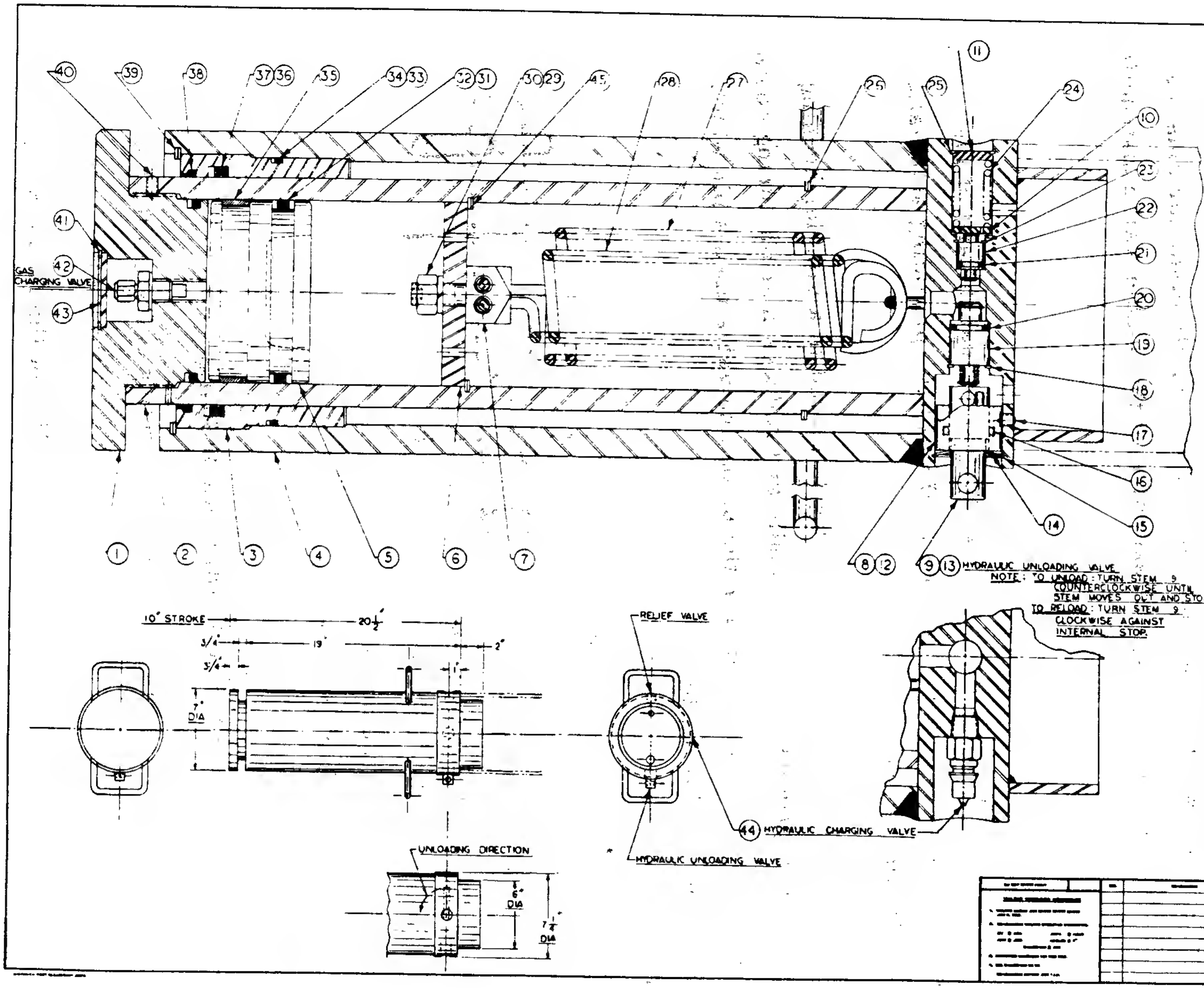
This design differs from Model 520 mainly in that the end of the accumulator cylinder is threaded on, as in Model 510, providing automatic release of nitrogen pressure.

The larger unloading valve cartridge is placed in a simpler housing which affords good protection for the handle and reduces manufacturing costs. The first actuator which was made for the unloading valve used a pin which dropped into a slot, allowing the valve spindle to move out, thus releasing the pressure. This motion was too violent, and resulted in sheared and bent pins, and damaged slots. The redesign uses a ramp on which the pin moves, plus a Belleville spring which allows the housing to move slightly to absorb the valve-opening energy.



QUESTIONS REGARDING REDESIGNS

1. Evaluate the stresses in the hydraulic unloading valve pin (which slides on the ramp in part 8) starting with full hydraulic pressure.
2. Design retraction springs to permit retraction of the Model 530 in 5 seconds with no external load.

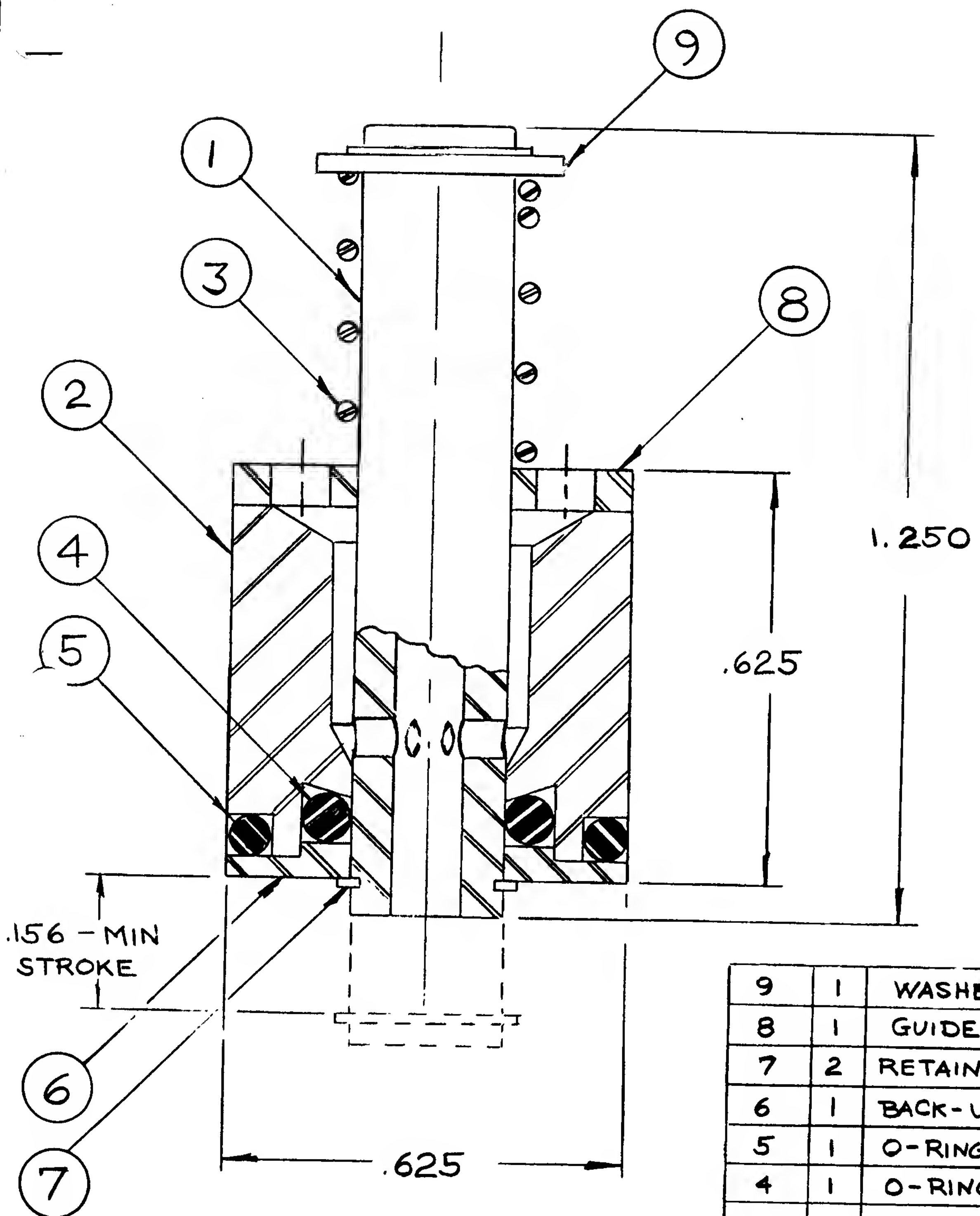


ITEM NO	REQ	DESCRIPTION
45		RETAINING RING
44	1	HYDRAULIC CHARGING VALVE
43	1	GUARD PLATE
42	1	GAS CHARGING VALVE
41		RETAINING RING
40	1	SET SCREW
39	1	RETAINING RING
38	1	SCRAPER RING
37	1	BACK-UP RING
36	1	QUAD RING
35	1	PISTON WEAR RING
34	1	BACK-UP RING
33	1	O-RING
32	3	BACK-UP RING
31	2	QUAD RING
30	1	LOCK WASHER
29	1	HEX NUT
28	1	INNER RETURN SPRING
27	1	OUTER RETURN SPRING
26	1	RETAINING RING
25	1	RETAINING RING
24	1	RELIEF VALVE SPRING
23	1	RETAINING RING
22	1	RELIEF VALVE CARTRIDGE
21	1	O-RING
20	1	O-RING
19	1	UNLOADING VALVE CARTRIDGE
18	1	RETAINING RING
17	1	SET SCREW
16	1	O-RING
15	1	RETAINING RING
14	1	SPRING
13	1	PIN
12	1	STOP PIN
11	1	RELIEF VALVE SPRING GUARD
10	1	RELIEF VALVE SPRING SUPPORT
9	1	HYD. RELEASE PLUNGER
8	1	RELEASE PLUNGER HOUSING
7	1	RETURN SPRING HOLDER
6	1	HYDRAULIC SNUBBER
5	1	ACCUMULATOR PISTON
4	1	HOUSING
3	1	GLAND BEARING
2	1	ACCUMULATOR TUBE
1	1	FRICTION HEAD

Lebco INC.

LEDEEN DYNAPROP
MODEL 330
SPRING RETURN TYPE
ROOF SUPPORT

M.E.C. 11-7-63 FULL D82082



ITEM NO	REQ	DESCRIPTION
9	1	WASHER
8	1	GUIDE
7	2	RETAINING RING
6	1	BACK-UP RING
5	1	O-RING
4	1	O-RING
3	1	SPRING
2	1	SPACER
1	1	PISTON

TOLERANCES DECIMALS .XX± .XXX± .005	DYNAPROP UNLOADING VALVE CARTRIDGE	Ledeen INC.
SCALE 4:1		HL-01071

ECL 129D

TO SUPPORT A MOUNTAIN

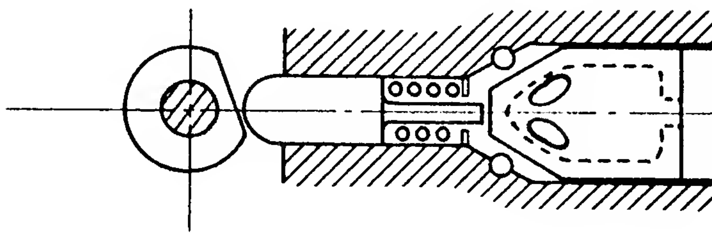
Part D

The Spanseal Unloading Valve
Case History of a Detail

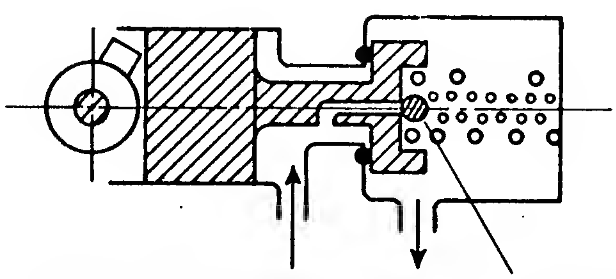
Reprinted from EDP Report Number 6-64. Written by R.B. McKee.

Release Valve - Case History of a Detail

For the first prototype of the Dynaprop, a sensible decision was made to use a commercially available valve cartridge (Figure 1). Sealing force in this valve is provided by the pressure inside. In the first Dynaprops, the

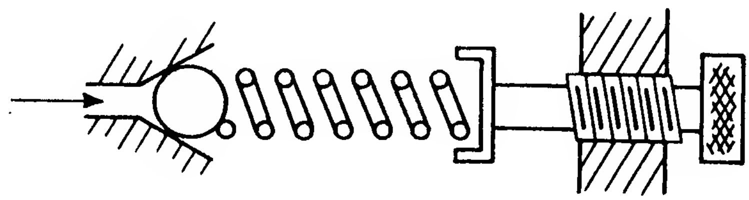


pressure was manually released by forcing the valve shuttle away from its seat with the cam and tappet arrangement shown here. When the pressure to be released is about 4,000 psi, the forces required for release are commensurately high. This was soon brought to Howard Ledeen's attention by failures of the cam fastening and buckling failures of the operating tappet. Also, the high velocity oil flow during release damaged the seal. For a

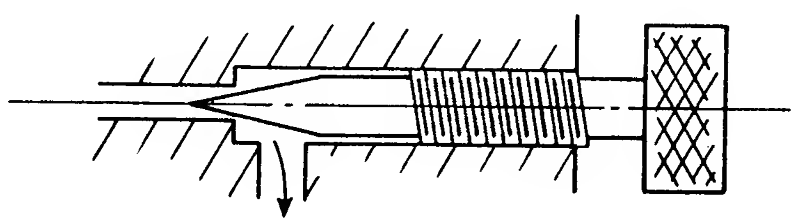


second generation prop, the decision was made to use a release cartridge whose spool would not have to be moved against pressure during release. Such a valve is in general use in European hydraulic props. This is a combination relief-unloading valve. The force required to open the valve - and the sealing pressure - increases as the pressure increases.

The relief valve in European props, which acts to release oil at some preset pressure for safety, is often simply a ball held against a seat by a spring.

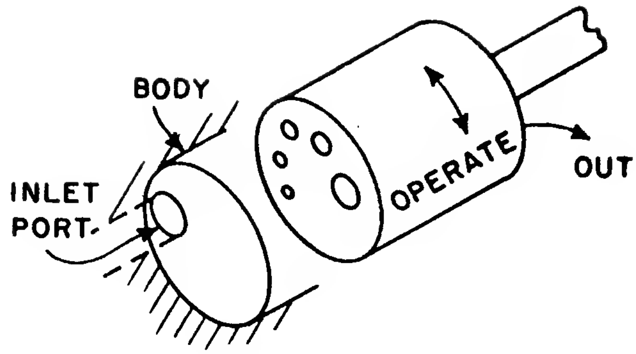


One of the detail parts made by Ledeen for its gas line valve operators is a throttling valve with a special "orifice flow" feature. This is best understood by comparison with the more common "needle" type of throttling valve. In this latter type of valve, the initial opening, while representing a sizeable



flow area, is an annulus of very small thickness. The valve is susceptible to damage from dirt and simply from the high velocity flow over the sealing surface.

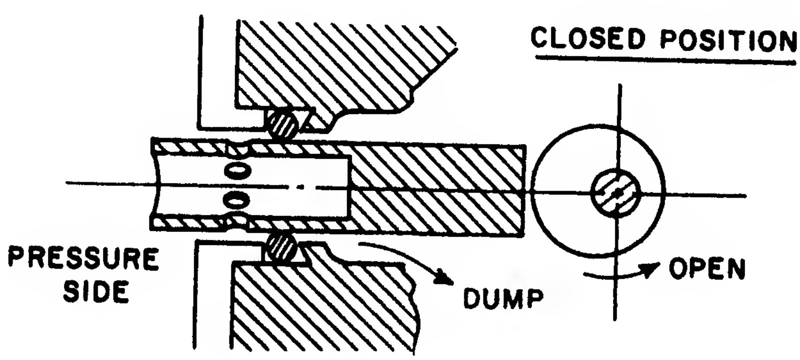
The "orifice flow" throttling valve operates by requiring the fluid to flow through round, square edge orifices of varying size and number. Thus, to obtain more flow, or less pressure drop, more or larger holes are provided



for the flow stream. This is done by a cylindrical valve body whose end, provided with appropriate holes, is lapped to a valve body containing an inlet port. Thus, the flow area-rotation relation is achieved by size and number of holes, and the effects of flow erosion are kept away from the sealing surfaces.

The "Span Seal" Cartridge

The decision was made to utilize the desirable features of the "orifice flow" throttling valve in a new unloading valve whose spool would not have to move "upstream". The shape and mode of operation of the new valve were constrained by the need for field modification of the series 300 Dynaprops, that is, to replace a cylindrical valve cartridge operated by a linear motion. The throttling action was not needed, so one set of holes which are all uncovered at once are used. Sealing is by means of an O ring. The spool moves (activated by pressure) to the "open" position (to the right in this sketch), causing the operating cam to turn on the shaft so that its maximum lift is in the "closed" position.



An interesting feature of the valve is that the natural tendency of the "O" ring seal to drop into the valve ports is countered by the oil itself which pushes the ring back into its groove. The main flow takes place after the valve parts have moved past the seal.

The same valve design is used as a pressure relief valve by replacing the cam and tappet with a spring.

The action of the "span seal" valve as a relief valve differs from the more conventional spring-loaded ball valve in that the valve must move before any unloading takes place. This means that the precompression of the valve spring must correspond to a lower pressure than that at which the unloading is to take place. The result is a greater uncertainty about the pressure "setting" of each valve. Howard Ledeen's decision was that "tightness" (no leaks) and "durability" of this valve design were the most important design factors, and justified some lack of precision in the relief pressure.

INSTRUCTOR'S NOTES
by G. Kardos

TO SUPPORT A MOUNTAIN

This case on the development of a special item of mining hardware can be used by the instructor in several ways. It tells of the development of a hydraulically actuated mine prop and takes the design through several iterations. The case is divided into segments each of which may be assigned and discussed separately.

The questions posed by the authors of the case at the end of each part make excellent design problem assignments. Since the answers to the questions are not given but only hinted at, the case really serves as a term of reference for project work.

Part A of the case poses the requirements. Students can be asked to define the requirements as a specification, the written requirements, the implied requirements, and the safety requirements. Conceptualization and creativity can be applied at this stage.

For class discussion I have posed the problem that the class act as the engineering team of a competitor who imports friction props, Part A of the case being a report from marketing on future requirements. The class is then asked to formulate an engineering strategy indicating cost and time required to produce field trial units.

The use of a pneumatic accumulator in Part B gives an opportunity either by assignment or by class discussion to apply the gas laws. Typical questions which can be posed for this purpose:

1. What will be the gas pressure in the accumulator when the mine prop is supporting rated load?
2. How much oil will have to be pumped into the prop to have it act as a suitable support?
3. If oil is pumped into the prop sufficient to support rated load what will be the minimum pressure in the prop after 24 hours?

To answer these questions properly will require an understanding of the mine prop's function and the gas laws especially differentiating between isothermal and adiabatic compression.

Part C of the case gives further developments of the mine prop. Discussion on evolution of the design will bring out several interesting features. Although the double cylinder construction of the 510 unit is attributed to safety, it is quite apparent that it was arrived at by keeping accumulator parts common with Model 300.

Part D can be used as a starting point for detail design project on unloading valves. Several iterations are shown. By no means is the solution ideal. The student can design a better unloading valve. The project is small enough that detail drawings can be asked for with required dimensions and tolerances.

The question of retraction time is posed in several parts of the case and the student can carry out these calculations. Not all the dimensions are available but they need not be. The student should be required to make assumptions and estimates. The fact that the oil must pass through several orifices can lead to interesting results and the assumptions made will shed light on the function of the mine prop.

At the completion of the case it is constructive to go through once more the process of defining the requirements of a mine prop. This will show the students that specifications and requirements are not fixed but develop as the design evolves and field experience is accumulated.

An alternate assignment is to ask the students to prepare a user's specification sheet so that miners unfamiliar with the dynamic mine prop will use them properly.